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Hydraulic performance evaluation of different emitters at different operating pressures

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Abstract
A field experiment was conducted to evaluate the performance of drip irrigation systems at "Irrigation Park" of College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh during the year 2018. An attempt was made to test the hydraulic performance of emitters of 2, 4, 8 and 14 lph for different operating pressures of 0.75, 1.00, 1.25, 1.5, 1.75 and 2.00 kg/cm^2. Pressure discharge relationship, Christiansen's uniformity (CU), manufacturing coefficient of variation (CVm), emission uniformity (EU) and distribution uniformity (DU) of non-pressure compensating emitters were assessed in the study. It was concluded that the designated discharge of emitters was obtained at 1.00 kg/cm^2 operating pressure. The pressure discharge relationship follows a power function having exponent value less than 0.5 for non-pressure compensating emitters. The CVm was mostly less than 0.0544 for all operating pressures. CU, DU and EU were found to be greater than 90% for entire operating pressure range. Value of CU, CVm, EU and DU were found to be in excellent and very good categories for all emitters as per ASABE standard.

Keywords: Drip irrigation, distribution uniformity, emission uniformity, performance evaluation, uniformity coefficient

1. Introduction

Water scarcity and lack of water resource management technologies are common challenges faced by majority of small and marginal farmers in fast developing countries like India. In order to solve the problem of water shortage in agriculture, it is necessary to develop water-saving management technologies. India, consuming almost 80% of its total water resources for agriculture sector, needs to reduce the consumption of water and nutrients to substantial levels using advanced scientific methods of irrigation like drip and sprinkler irrigation systems (Dhawan, 2017) [4]. Drip irrigation has the greatest potential for the efficient use of water and fertilizers. For minimizing the cost of irrigation and fertilizers, adoption of drip irrigation with fertigation is essential as it maximizes the nutrient uptake while using minimum amount of water and fertilizer (Roma and Arun, 2014) [10]. The overall irrigation efficiency of micro irrigation normally ranges from 70 to 90% as compared to 30 to 45% in case of surface irrigation owing to reduced loss of moisture through evaporation and runoff (Yadav *et al*., 1993) [13]. Drip irrigation system increases yield by 15-25% depending on crop type when compared with surface irrigation system. Drip irrigation reduces weed population by 50 to 60% and saves 30 to 50% water without affecting crop yield. In addition, it improves the fertilizer use efficiency, hastens the maturity of crop and improves the quality of the produce (Yadav *et al*., 1993) [13].

In drip irrigation system, emitters are a major component dealing with water distribution and water use efficiencies. Quality and precise performance of emitters play a major role in uniform distribution of water to get optimum water use efficiency and yield. In order to determine uniformity of water application, it is necessary to evaluate emitter discharge uniformity and system performance. So, present study was emphasized on the technical and hydraulic evaluation of different online and inline emitters in field conditions.

2. Materials and Methods

2.1 Study Area

The experiment was conducted at "Irrigation Park", Soil and Water Conservation Engineering Department, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh. The study area is located at 21.5° N latitude and 70.1° E longitude with an altitude of 74 m above mean sea level.

The climate of the area is subtropical and semi-arid type with an average annual rainfall of 900 mm and average annual pan evaporation of 5.6 mm/day. January is the coldest month with mean monthly temperature varying from 7 °C to 10 °C and maximum monthly temperature is recorded in the month of May varying between 35 °C to 45 °C. Also, the variation in the monthly mean relative humidity, wind speed, bright sunshine hours and pan evaporation were from 62.2% to 74.4%, 3.5 km/h to 6.6 km/h, 8.1 to 9.5 h and 4.6 to 9.6 mm, respectively.

2.2 Hydraulic Performance of Drip Irrigation System

Hydraulically, the flow through the network of micro irrigation pipes and outlets is considered as a turbulent flow through smooth pipes. In drip irrigation system, water is delivered precisely through the emitters. The emitting pipes generally used in Saurashtra region have discharge rates of 2 lph and 4 lph with 0.40 and 0.60 m emitter spacing in inline drip irrigation system and 8 lph and 14 lph with 1 m emitter spacing. The former shows no variation in discharge due to the corresponding change in the pressure head but in the latter the discharge changes with pressure. Sufficient scientific information is not available on the flow characteristics of different emitters under various operating pressure in India. Hence, it is necessary to evaluate the hydraulic performance of drip irrigation system. Keeping this in view, a field test was undertaken to evaluate the hydraulics of non-pressure compensating emitters of 2, 4, 8 & 14 lph discharge rating with pressure rating of 0.75, 1.00, 1.25, 1.50, 1.75 and 2.0 kg/cm^2.

2.2.1 Pressure discharge relationship

The pressure discharge relationship for emitters was expressed by the following formula (Karmeli, 1977, Wu and Gitlin, 1977) [7, 12].

$Q = KH^X$

Where,

Q is discharge rate of drippers (lph),

K is discharge coefficient,

H is pressure head (kg/cm^2) and

X is dripper flow exponent.

2.2.2 Uniformity coefficient

The degree of emitter flow variation is expressed by the uniformity coefficient. Uniformity coefficient was calculated by the following equation (El-Nemr, 2012) [5]. It gives the information about the efficiency with which water is distributed in the field.

$$CU = 1 - [\frac{\sum_{i=1}^{n} q_i - q_a}{q_a \times n} \times 100]$$

Where,

CU is coefficient of uniformity (%),

n is number of observed emitters,

q_i is emitter flow rate(lph) and

q_a is average of emitters flow rates (lph).

Table 1: Micro-irrigation system uniformity classification based on uniformity coefficient

CU (Uniformity Coefficient)	Interpretation
90% or greater	Excellent
80 to 90%	Very good
70 to 80%	Fair
60 to 70%	Poor
less than 60%	Unacceptable

(Source: ASABE Standard EP 458, 1989) [1]

2.2.3 Coefficient of manufacturing variation

Coefficient of manufacturing variation is defined as the ratio of the standard deviation of flow to the mean flow for a sample number of emitters. Coefficient of Variation (CV_m) is a statistical parameter expressed below (Madramootto, 1988) [8].

$$CV_m = \frac{S}{q}$$

Where,

CV_m is manufacturing coefficient of variation,

q is average emission rate of sample and

S is sample standard deviation.

$$S = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (q_i - q_a)^2}$$

Where,

n is number of observed emitters,

q_i is emitter flow rate (lph) and

q_a is average of emitters flow rates (lph).

Table 2: Classification of coefficient of manufacturer's variations

Emitter type	Manufactures Coefficient (CV_m)	Interpretation
Line Source	< 0.10	Good
	0.10-0.20	Average
	>0.20	Marginal to unacceptable
Point Source	< 0.05	Excellent
	0.05- 0.07	Average
	0.07-0.11	Marginal
	0.11- 0.15	Poor
	> 0.15	Unacceptable

(**Source:** ASABE Standard EP 405.1, 2008) [2]

2.2.4 Emission uniformity

Emission uniformity shows the relationship between minimum and average emitter discharge. To estimate the emission uniformity for a proposed drip irrigation system design, the following equation was used (Sharma, 2013) [11].

$$EU = 100[1-1.27\ CV/ (\sqrt{n})]\ (q_{min}/q_{avg})$$

Where,

EU is emission uniformity, CV is manufacturer's coefficient of variation, n is number of emitters per lateral for crop, q_{min} is minimum emitter discharge rate for the minimum pressure in the section (lph) and q_{avg} is average emitter discharge rate for the all emitter on the lateral (lph).

Table 3: Recommended classification of emission uniformity

EU range	Merriam and Keller (1978) [9]	IRYDA (1983) [6]
>94%	Excellent	Excellent
90-94%	Excellent	Good
86-90%	Good	Good
80-86%	Good	Acceptable
70-80%	Acceptable	Poor
<70%	Poor	Unacceptable

2.2.5 Distribution uniformity

Distribution uniformity (DU) shows the relationship between the average flow rate of the emitters in the lowest quartile and the average flow rate of all emitters. To estimate the distribution uniformity for a proposed drip irrigation system design, the following equation was used (Merriam and Keller, 1978) [9].

$$DU = \left(\frac{q_n}{q_a}\right) \times 100$$

Where,
DU is distribution uniformity (%),
q_a is average emitter discharge rate (lph) and q_n is average flow rate of the emitters in the lowest quartile (lph).

Table 4: Classification of distribution uniformity

Distribution Uniformity (DU) %	Merriam and Keller (1978) [9]
<70%	Poor
70-90%	Good
>90%	Excellent
100%	Impossible

3. Results and Discussion

Emitting pipe with discharge rating of 2 lph & 4 lph and emitter with discharge rating of 8 lph & 14 lph were selected for measuring discharge variation at various operating pressures *viz.* 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00 kg/cm^2. For each operating pressure, the volume of 9 individual emitters was collected in the catch can for a specified duration of 30 minutes and was accurately measured using measuring cylinder. The average discharges of emitters at various operating pressures are given in Fig. 1. Which indicated that minimum discharge of emitters was at 0.75 kg/cm^2 for all emitters, while it was found maximum at 2.00 kg/cm^2 operating pressure for all emitters. The results clearly indicated that as the operating pressure increased, discharge of emitters also increased.

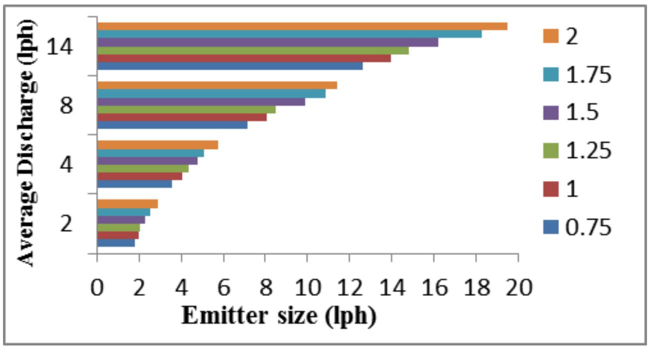

Fig 1: Discharge rate of different emitters at various pressure

3.1 Pressure Discharge Relationship

A pressure discharge relationship for emitters was developed for 2 lph, 4 lph, 8 lph, & 14 lph of inline and online emitters and depicted in Table 5. High coefficient of determination (R^2) values were obtained for the developed model as given in Table 5.

Table 5: Developed models of the pressure discharge relationship for emitters

Emitter rating	Developed model	Discharge coefficient (K)	Exponent (x)	Goodness of fit (R^2)
2 lph	$y = 1.9693x^{0.4642}$	1.9693	0.4642	$R^2 = 0.9445$
4 lph	$y = 4.0127x^{0.4514}$	4.0127	0.4514	$R^2 = 0.9725$
8 lph	$y = 8.0588x^{0.4944}$	8.0588	0.4944	$R^2 = 0.9702$
14 lph	$y = 13.976x^{0.4425}$	13.976	0.4425	$R^2 = 0.9648$

Table 5 shows that the discharge coefficient was achieved respectively as 1.9693, 4.0127, 8.0588 and 13.976 and exponent was attained respectively as 0.4642, 0.4514, 0.4944 and 0.4425 for 2 lph, 4 lph, 8 lph and 14 lph emitters respectively. From the study, it was found that exponent value of emitter approached 0.5. It was concluded that the designated exponent (x) and discharge coefficient (K) of emitters were obtained when the operating pressure was kept at 1.00 kg/cm^2.

3.2 Uniformity Coefficient

Christiansen's (1942) formula was used to calculate uniformity coefficient of emitter at various operating pressures. The highest CU obtained were 97.12, 99.25, 98.75 and 98.70% at 1 kg/cm^2 operating pressure for 2 lph, 4 lph, 8 lph and 14 lph emitters respectively. As per ASAE (1989) [3] recommendation, all emitters fall under excellent category. Fig. 2 shows the CU of different emitters at various operating pressure.

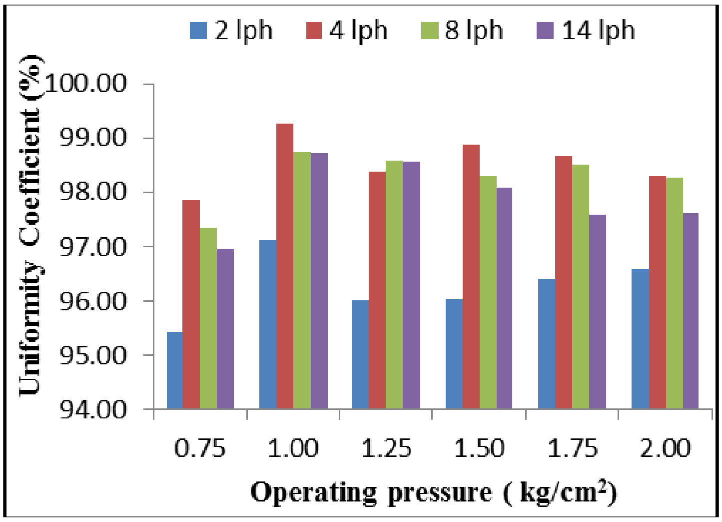

Fig 2: Uniformity coefficient of emitters at various operating pressures

3.3 Manufacturing Coefficient of Variation
The manufacturing coefficient of variation (CVm) is used as a measure of the anticipated variation in discharge for a sample of different drippers. Maximum CVm was obtained respectively as 0.0351, 0.0087, 0.0149 and 0.0150 for 2 lph, 4 lph, 8 lph and 14 lph emitters respectively at operating pressure 1 kg/cm^2, which can be categorized as excellent and good as per ASABE (2008) [2] standards. Fig. 3 shows the Manufacturing coefficient of variation of different emitters at various operating pressure.

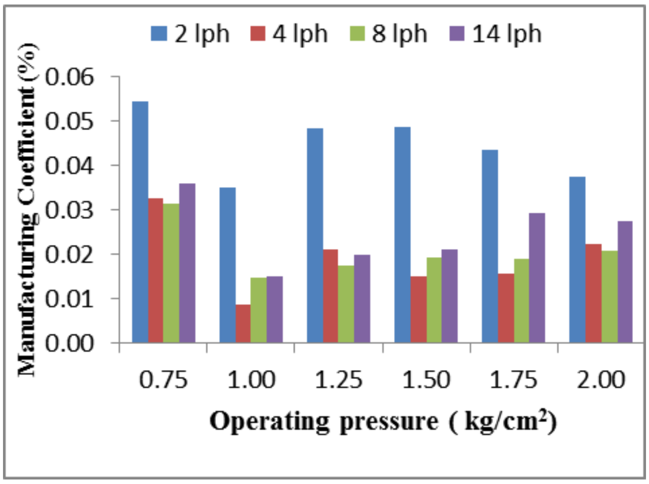

Fig 3: Manufacturing coefficient of variation of emitters at different rating

3.4 Emission Uniformity
Results revealed that the maximum EU was obtained respectively as 93.61, 98.78, 97.43 & 97.64% for 2 lph, 4 lph, 8 lph and 14 lph emitters which can be categorized as excellent as per Merriam and Keller (1978) [9] recommendation and categorized as excellent and good as per IRYDA (1983) [6] recommendation. Fig. 4 shows the Emission uniformity of variation emitters at various operating pressure.

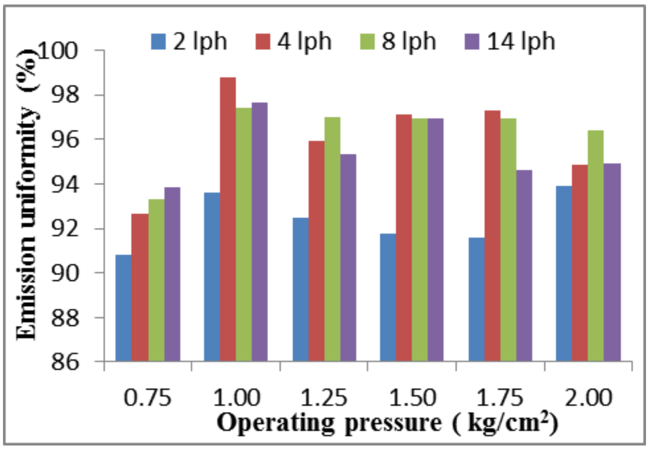

Fig 4: Emission uniformity of variation of emitters at various operating pressure

3.5 Distribution Uniformity
The distribution uniformity of various emitters of different size at different operating pressures is presented in Table 6. The results showed that all the emitters performed better at the pressure range of 0.75 to 2.00 kg/cm^2. Distribution uniformity obtained were 93.61 to 96.00%, 95.53 to 99.15%, 94.44 to 97.78%, 94.18 to 97.80%, 93.28 to 97.90 and 95.40 to 97.51 for various emitter operating pressure 0.75, 1.00, 1.25 1.50, 1.75 and 2.00 kg/cm^2 respectively as shown in Fig. 5.

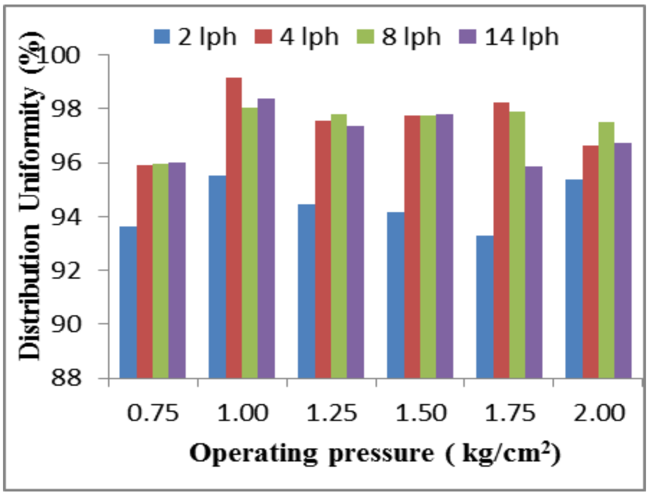

Fig 5: Distribution uniformity of emitters at various operating pressures

4. Conclusion
The various parameters to evaluate the performance of drip irrigation system viz., pressure discharge relationship, uniformity coefficient, manufacturing coefficient of variation, emission uniformity and distribution uniformity were calculated for field condition. The hydraulic performance of 2, 4, 8 and 14 lph emitters were tested at operating pressure of 0.75 to 2.00 kg/cm^2. Best discharges of emitters can be obtained when the operating pressure was kept at 1 kg/cm^2. The values of CU, CVm, EU and DU obtained at 1 kg/cm^2 (Table 6) falls under excellent and very good category for emitters as per the ASABE standard.

Table 6: Performance parameters to evaluate drip irrigation system at 1 kg/cm^2 operating pressure

Emitter	CU	CVm	EU	DU
2 lph	97.12	0.0351	93.61	95.53
4 lph	99.27	0.0087	98.78	99.15
8 lph	98.75	0.0149	97.43	98.06
14 lph	98.70	0.0150	97.64	98.37

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